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ASR79-109

ORBITAL TRANSFER VEHICLE
ADVANCED EXPANDER CYCLE
ENGINE POINT DESIGN STUDY

CONTRACT NO. NAS8-33568

BIMONTHLY PROGRESS REPORT NO. 1

12 OCTOBER 1979

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER, ALABAMA 38142

PREPARED BY

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INTRODUCTION AND SUMMARY

The OTV Advanced Expander Cycle Engine Design Study is an 11-month technical effort, organized into 9 technical tasks and one reporting task. The program efforts are directed to generate a performance-optimized engine system design for an advanced LOX/hydrogen expander cycle engine. The analyses of the engine system and components and resulting drawings will be of sufficient depth to result in accurate definition of engine performance, engine and component weights/envelopes, engine control techniques, turbopump efficiencies, and new technology requirements.

The point design study is organized to take advantage of recently performed and in-progress technical efforts at Rocketdyne on the expander cycle engine that benefit the proposed program both in terms of scope and depth of program results, and in tools such as the steady-state and transient engine models that are operational for the contractual tasks. In addition, maximum use will be made of advanced expander cycle engine optimization study results from contracts NAS8-32996, NAS8-32999, and NAS8-33444.

The program, as planned and structured, will provide the in-depth analysis and design efforts necessary to define and establish a point design advanced expander cycle engine. Rocketdyne desires to define the best overall engine concept for the orbit transfer vehicle (OTV) and fully recognizes the advantages of the expander cycle in terms of simplicity, reliability, and system safety. In addition, recent studies on performance improvements to the expander cycle have permitted significant increases in chamber pressure that have added substantially to engine delivered specific impulse. These factors make the expander cycle engine an extremely attractive candidate for OTV propulsion.

So that the OTV Expander Cycle Engine Optimization and Point Design Engine Studies can proceed with a logical set of study guidelines, a set of general criteria and guidelines for the study has been delineated. These guidelines may be revised during the course of the study by the contracting officer's representative (COR) to reflect new guidelines as they are developed or as modifications to existing guidelines become established. The general guidelines for the OTV engine as established by NASA, are summarized in Tables 1 and 2. These guidelines will be used throughout the program effort and will provide a basis for the optimization analysis, OTV engine design concept selection, engine design efforts, and the supporting areas such as heat transfer, stress and fluid flow analysis.

The contracted effort includes nine technical tasks and one reporting task. The scheduling for these tasks is shown in Fig. 1. Consistent with the requirements identified in Tables 1 and 2, the following task goals have been identified.

Task 1. Steady-state Computer Model - Develop a detailed computer model of the engine system steady-state operation. This program shall balance the cycle pump and turbine powers for given chamber pressures and mixture ratios in reasonably wide bands covering both the high and low thrust operating points. It shall include tables of data to predict specific impulse and thrust chamber heat transfer parameters. Duct resistances and component characteristics shall be input in a manner to facilitate revisions and updates as more refined analysis and test data becomes available. The program shall be programmed to be compatible with the Univac 1108 requirements and be provided to the NASA on magnetic tape along with a sample case and user's manual.

TABLE 1. ENGINE REQUIREMENTS

1. The engine will operate as an expander cycle with liquid hydrogen and liquid oxygen propellants.

2. Engine vacuum thrust will be 15K pounds at an engine O_2/H_2 weight flowrate mixture ratio of 6.0, with programmed mixture ratio in the range 6 to 7.

3. Engine length with the two-position extendible nozzle retracted will be no greater than 60 inches.

4. Engine design and materials technology are to be based on 1980 state of the art.

5. The engine must be capable of accommodating programmed and/or command variations in mixture ratio over an operating range of 6:1 to 7:1 during a given mission. The effects on engine operation and lifetime must be predictable over the operating mixture ratio range.

6. The propellant inlet temperature will be 162.7 R for the oxygen boost pump and 37.8 R for the hydrogen pump. The boost pump inlet NPSH at full thrust will be 2 feet for the oxygen pump and 15 feet for the hydrogen pump.

7. The service free life of the engine cannot be less than 60 start/shutdown cycles or 2 hours accumulated run time, and the service life between overhauls cannot be less than 300 start/shutdown cycles or 10 hours accumulated run time. The engine will have provisions for ease of access, minimum maintenance, and economical overhaul.

8. The engine when operating within the nominal prescribed range of thrust, mixture ratio, and propellant inlet conditions will not incur during its service life chamber pressure oscillation, disturbances, or random spikes greater than ±5% of the mean steady-state chamber pressure. Deviations to be expected in emergency modes will be predictable.

9. The engine nozzle is to be a contoured bell with an extendible/retractable section.

10. Engine gimbal requirements are +15 degrees and -6 degrees in the pitch plane and ±6 degrees in the yaw plane.

11. The engine is to provide gaseous hydrogen and oxygen autogenous pressurization for the propellant tanks.

12. The engine is to be manrated and capable of providing abort return of the vehicle to the Orbiter orbit.

13. The engine design will meet all of the necessary safety and environmental criteria of being carried in the Orbiter payload bay and operating in the vicinity of the manned orbiter.

14. The engine must be adaptable to extended low-thrust operation of approximately 1K vacuum thrust. Kitting of the engine's injectors, turbine flow area, and other constraining components may be considered as well as the inclusion of a heat exchanger to gasify the LOX for low-thrust operation. Engine mixture ratio will be maintained as high as cooling and power constraint allow (but no greater than 7:1).

TABEL 2. STRUCTURAL DESIGN CRITERIA

The following minimum safety and fatigue life factors will be utilized. These factors are only applicable to designs whose structural integrity will be verified by comprehensive structural testing which demonstrates adherence to the factors specified below. Where structural testing is not feasible more conservative structural design factors will be supplied by NASA.

1. The structures will not experience gross (total net section) yielding at 1.1 times the limit load nor will failure be experienced at 1.4 times the limit load. For pressure containing components, failure will not occur at 1.5 times the limit pressure.

2. Limit load is the maximum predicted external load, pressure, or combination thereof expected during the design life.

3. Limit life is maximum expected usefulness of the structure expressed in time and/or cycles of loading.

4. The structure will be capable of withstanding at least four times the limit life based on lower bound fatigue property data.

5. Components which contain pressure will be pressure tested at 1.2 times the limit pressure at the design environment, or appropriately adjusted to simulate the design environment, as a quality acceptance criteria for each production component prior to service use.

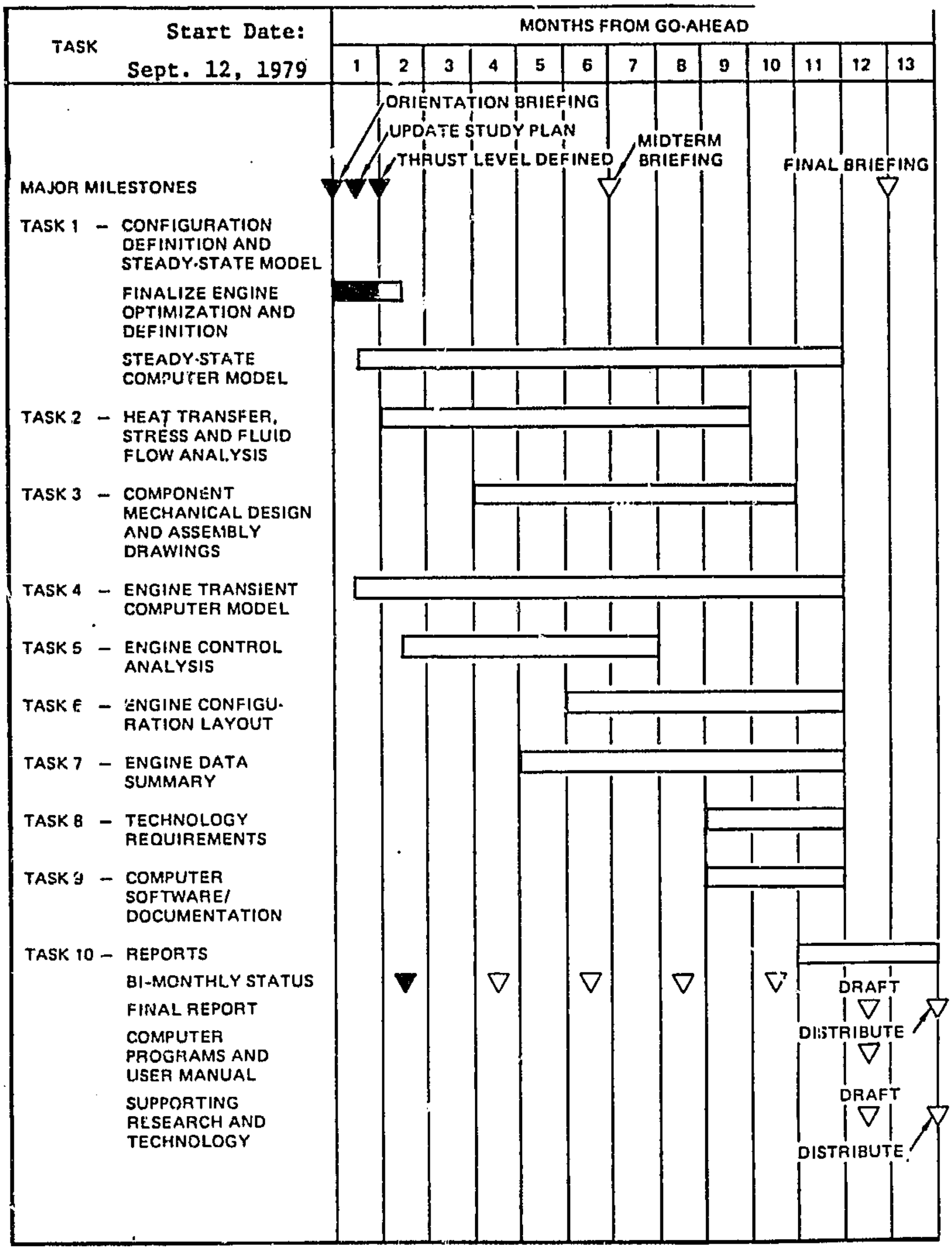

Figure 1. Advanced Expander Cycle Engine Point Design Study

Task 2. Heat Transfer, Stress, and Fluid Flow Analysis - Perform heat transfer, stress, and fluid flow analysis on the thrust chamber/nozzle, lox turbopump and hydrogen turbopump in support of the mechanical design.

Task 3. Component Mechanical Design and Assembly Drawings - Provide mechanical design and assembly drawings for the components below. The mechanical designs and drawings shall be of sufficient depth to reveal manufacturing difficulties, allow leakage and cooling flows to be assessed, calculate weights, and determine technology requirements of the following subassemblies: thrust chamber and nozzle, extendible nozzle actuating mechanism and seal, lox turbopump, hydrogen turbopump, and propellant control valves.

Task 4. Engine Transient Simulation Computer Model - Develop a digital transient simulation computer model for the engine system. This program shall be a companion program to the steady-state computer model (Task 1) and shall evaluate engine parameters during commanded thrust and mixture ratio transitions. Program variable names and input data shall be as consistent with the steady-state program as possible. The program shall be programmed to be compatible with the Univac 1108 requirements and be provided to the NASA on magnetic tape along with a sample case and user's manual.

Task 5. Engine Control - Use the engine transient simulation model (Task 4) to determine effective control points and methods to achieve thrust and mixture ratio control. Determine suitable valve actuator drive methods considering power requirements, weight trade factors, reliability, and control precision. Define the controller requirements.

Task 6. Engine Configuration Layout - Provide an engine configuration layout drawing showing the packaging relationship of the primary engine components (i.e., boost pump, main turbopumps, control valves, thrust chamber, extendible nozzle/mechanism seal, and ducting). Consideration shall be given to Line Removable Units (LRU'S) in the packaging concept.

Task 7. Engine Data Summary - Define, with NASA's concurrence, a thrust and mixture ratio for low thrust engine operation. Develop a rigorous performance prediction and life prediction for the engine at the low thrust operating point selected above and at the high thrust operating point for mixture ratios of 6:1 and 7:1. Determine and tabulate the weights of the engine components called out in Task 3 and the total engine weight. Provide a summary of the engine dimensions which establish the physical envelope.

Task 8. Technology Requirements - Identify any new technology required to perform the detailed design, construction, and testing of this engine.

Task 9. Computer Software/Documentation - Original or modified software delivered by the contractor shall conform to Part 4.4, Restriction and Non-Standard Features, and Part 5.3, MSFC Computer Program Documentation Standard of the MSFC Programmer Procedures Manual.

Task Reports

During the performance of the contract the following reports will be submitted: The Study Plan, five Bimonthly Status Reports, Final Report, and Computer Program and User's Manual. In addition, a Supporting Research and Technology Report will be submitted at the completion of contracted effort.

DISCUSSION

PROGRAM MILESTONES

The Expander Engine Study Program began with an orientation briefing at MSFC to present details of the work to be accomplished. At this briefing, Rocketdyne presented the details of the program study plan, identifying tasks, their objectives, expected results, manhour allotments, and program milestones. Based on the results of the orientation meeting, an updating of the study plan was completed and released in accordance with contract requirements.

A thrust level of 15,000 pounds was defined in an 11 October 1979 telephone communication by the NASA Study Monitor, Dale H. Blount. Engine design mixture ratio of 6:1 and operating engine mixture ratio range of 6-to-7 were also confirmed during communication.

TASK 1. CONFIGURATION DEFINITION AND STEADY-STATE MODEL

Payload performance data for the expander cycle engine generated in the OTV Engine Phase A Extension effort for 100K pounds and 65K pounds Space Shuttle missions were examined to establish peak payload thrusts (Figs. 2 and 3, respectively). It is seen that peak payload for the 100K pound gross weight single engine case occurs at nearly 15,000 pounds thrust for both engine mixture ratios of 6:1 and 7:1. Peak payload at engine mixture ratio of 6:1 is 4 percent greater than at 7:1 mixture ratio. For the two-engine configuration peak payloads occur at engine thrust below 7,500 pounds (extrapolated) and are lower than single engine payloads.

For the 65K pound gross weight mission, peak payloads for the single engine configuration occur at nearly 10,000 pounds for both mixture ratios. Mixture ratio of 7:1 payloads are 5 percent lower than 6:1 payloads. Two engine configuration payloads occur at engine thrusts considerably below 10K pounds.

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FIGURE 2. AMOTV PAYLOADS FOR 100K SHUTTLE VS ENGINE THRUST

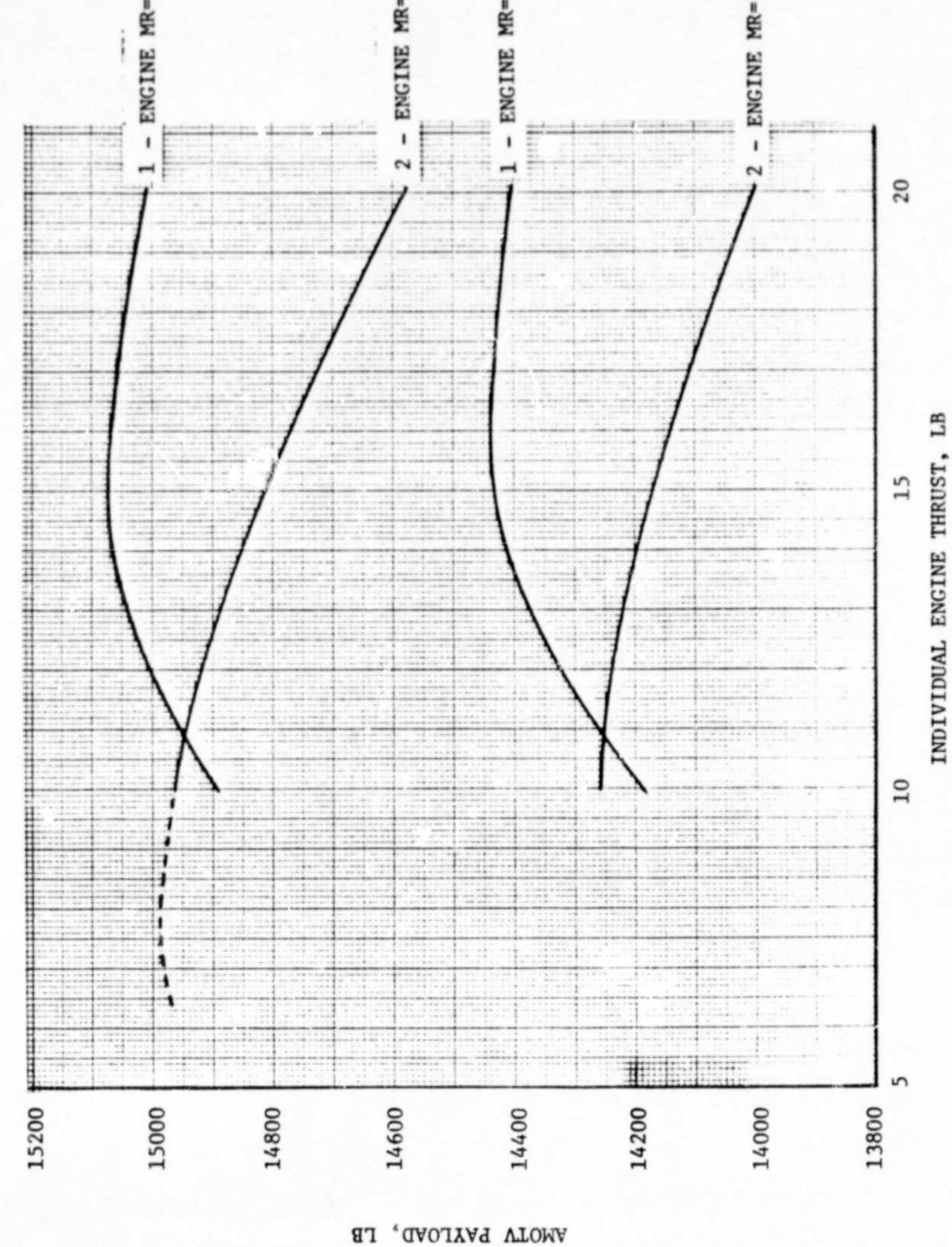
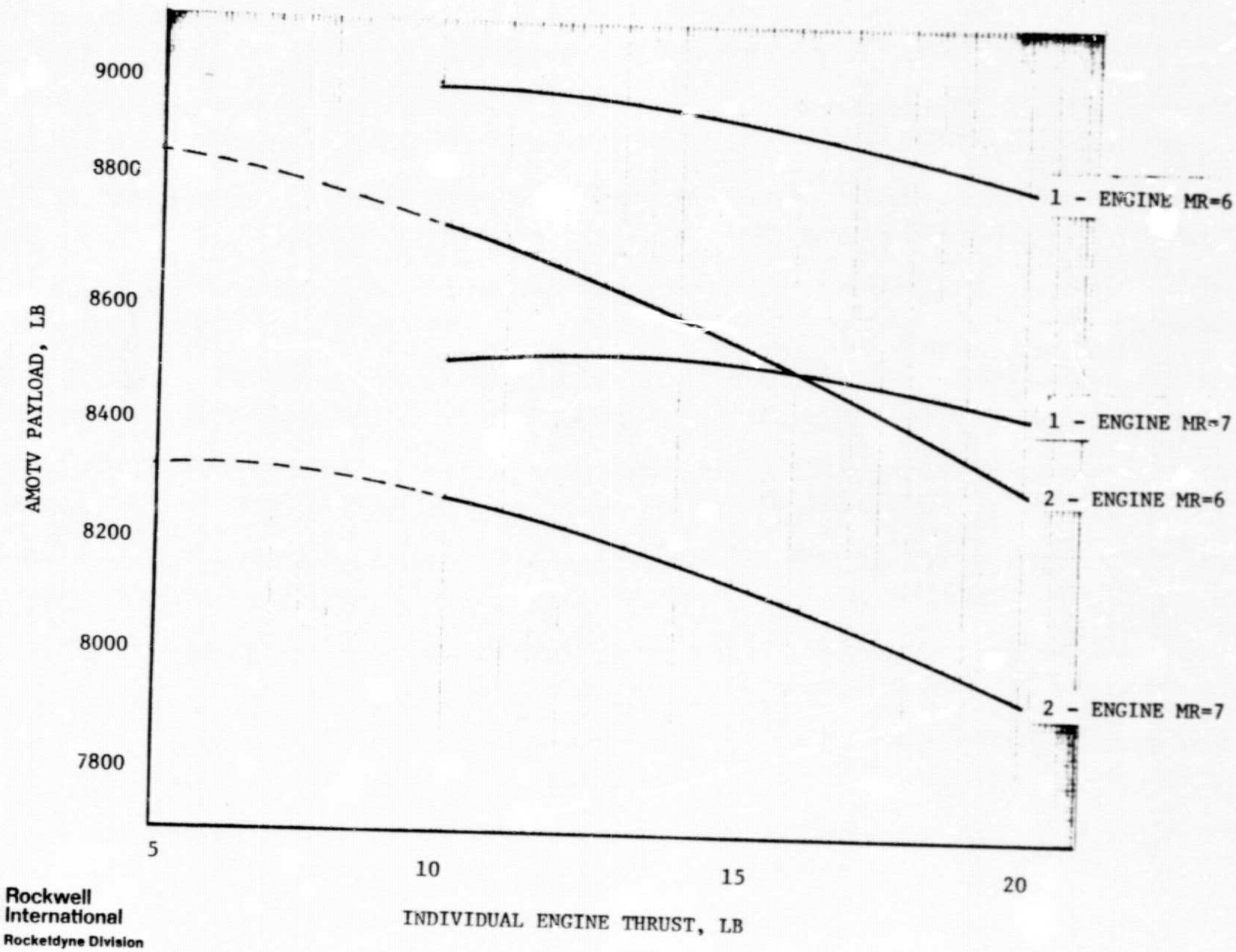


FIGURE 3. AMOTV PAYLOADS FOR 65K SHUTTLE VS ENGINE THRUST



The NASA selection of 15,000 pounds thrust and mixture ratio of 6:1 is consistent with the higher payload obtained with the single engine configuration for the 100K pounds gross weight mission. Because the vehicle inert weights in the above payload analysis are based on NASA TMX-73394 inert weight relationships, they are higher than those recently reported by OTV Vehicle Contractors' Studies. However, trends with thrust and mixture ratio are valid and are verified by vehicle contractors' results.

Advanced Expander Cycle Engine Trade Studies have been defined for the components shown in Table 3 in the areas indicated in the same table. A large number of the performance trade studies required have been performed in the OTV Phase A Extension Program. The remaining trade studies in Table 3 will be completed during the next report period when selection of the baseline engine configuration to be used in the Point Design Study will be made.

NEXT REPORT PERIOD

During the next report, after selection of the baseline engine configuration, work will begin in the modification of the existing engine steady-state and transient computer models (Tasks 1 and 4). Effort will also commence in Tasks 2, 3, and 5 (Fig. 1).

EXPENDITURES

Approximately 28 hours of the total planned man-hours were expended in Task 1 effort during this report period.

TABLE 3. ADVANCED EXPANDER CYCLE ENGINE TRADE STUDIES

Component (Or Area)
Combustor
Nozzle Extension
Main Pump Drive
Main Turbine Arrangement
Boost Pump Drive
Control System
Cooling Circuit
Nozzle Length, Area Ratio
Regenerative Heat Exchanger

Trade Study Area
Performance
State-of-the-Art
Cycle Life
Manufacturing, Handling and Maintainability
Complexity, Safety, Reliability
Man-Rating
Response and Start Losses
Off-Design Operation
Development and Production Costs